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Dodging a Malthusian Bullet in the 21st Century

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This bicentennial of the publication in 1798 of Thomas Malthus' *Essay on the Principle of Population* offers a felicitous opportunity to reexamine his apocalyptic thesis. That thesis holds that food supply increases linearly while population increases exponentially. It follows that, although food supply could exceed food needs at particular points in history, inevitably population outgrows food supply. Thus wars, disease, and other pestilence periodically are required to align population with food supply.

Because Malthus' thesis is temporally open ended, it can never be proven wrong. But Neo-Malthusians have kept the specter of global food scarcity before the public eye. Paddock and Paddock contended in 1967 (p. 8) that

> The famines which are now approaching will not, in contrast, be caused by weather variations and therefore will not be ended in a year or so by the return of normal rainfall. They will last for years, perhaps several decades, and they are, for a surety, inevitable. Ten years from now parts of the undeveloped world will be suffering from famine. In fifteen years the famines will be catastrophic and revolutions and social turmoil and economic upheavals will sweep areas of Asia, Africa, and Latin America.

In 1968 Paul Ehrlich stated in his prologue to *The Population Bomb* that

> The battle to feed all humanity is over. In the 1970s the world will undergo famines—hundreds of millions of people are going to starve to death in spite of any crash programs embarked upon now. At this late date nothing can prevent a substantial increase in the world death rate ….

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In 1972, the Club of Rome in *Limits to Growth* (Meadows) warned that "the human race may have little time to react to a crisis from exponential growth in a finite space." At the 1974 World Population Conference the FAO admonished that "... action must be initiated now to reduce the rate of population growth if we are to have any chance at all of meeting the world's food needs 25 years from now."

Lester Brown (see Brown and Cane; Brown, 1995) has provided a consistently gloomy outlook for global food security since the world food crisis of 1966-67. By 1991 he was saying that "As we enter the 1990s, the world has little to celebrate on the food front" (Brown 1991, p. 59). Later, Brown (1995) contended that China's cereal production would fall some 20 percent from the early 1990s level by year 2030 because agricultural land will shift to roads, reservoirs, industrial, urban, and other non-agricultural uses. That same process of economic growth attending urban-industrial development also would cause demand for food to rise steadily, causing a need to import well over 200 million tons of grain per year by 2030. Grain exporters will be unable to meet the rising demand, food prices will increase sharply, and consumers especially in the poor countries of South Asia and Africa will suffer several food shortages according to Brown.

Reality, fortunately, has not been kind to neo-Malthusian forecasts. World output of cereals, the major food source, has increased over 2.5 percent per year while population has increased under 2.0 percent per year since 1950, hence per capita cereal output has increased on average 0.5 percent or more per year (Mitchell et al., p. 1).

Gains in food supply relative to demand have reduced farm level food prices. Given its fairly open market to world trade, American farm prices are reasonably representative of world food prices. The U.S. parity price ratio (the index of prices received by farmers for crops and livestock divided by the index of prices paid by farmers for production inputs, including interest, taxes, and wage rates) fell by 50 percent from 1910-14 to 1986, and stood at 48 percent of the 1910-14 average in 1996 (Council of Economic Advisors, p. 412).

The combination of lower real food prices, economic growth, and greater access to resources by many formerly poor people reduced the number of chronically undernourished people in developing countries from 917 million 1969-71 to 839 million in 1990-92 (FAO 1996). Meanwhile the proportion of people undernourished in developing countries fell from 35 percent to 21 percent. Progress was substantial in all world regions except sub-Saharan Africa where both the number and incidence of chronically undernourished persons increased.

The sharp contrast between the gloomy forecasts and more rosy reality has turned neo-Malthusians into Cassandras—prophets whose repeated warning of misfortune are ignored. However, the following analysis suggests that past progress providing food security noted on this bicentennial of Malthus' *Essay* provides no basis for complacency regarding future food security. This report reviews two profound global trends: (1) crop yield growth, and (2) population growth, along with the implications of (1) and (2) for food security.

Supply Trends

Historic global yield and area trends are emphasized. Livestock and livestock products receive less attention partly because livestock output depends heavily on crop output and partly because data on livestock productivity trends are meager. Subsequent analysis examines trends in population and income components of food demand. Then crop supply projections are compared with demand (population and income) projections.

Categories of food and shares of global total calories derived from each in 1961 and 1995 are as follows:

	Global Share (%)	
	1961	*1995*
1. Cereals (maize, wheat, rice, millet, etc.)	50.1	49.4
2. Vegetables (green beans, cabbage, onions, tomatoes, etc.)	2.0	2.1
3. Pulses (dry beans, chick peas, groundnuts, peas, etc.)	3.9	2.2
4. Roots and tubers (cassava, potatoes, yams, etc.)	8.0	5.1
5. Oilcrops (soybeans, rapeseed, cottonseed, canola, etc.)	1.7	2.0
6. Meats (poultry, beef, pigmeat, lamb, etc.)	4.9	7.5
7. Other (dairy products, eggs, fruits, etc.)	29.4	31.7
	100.0	100.0

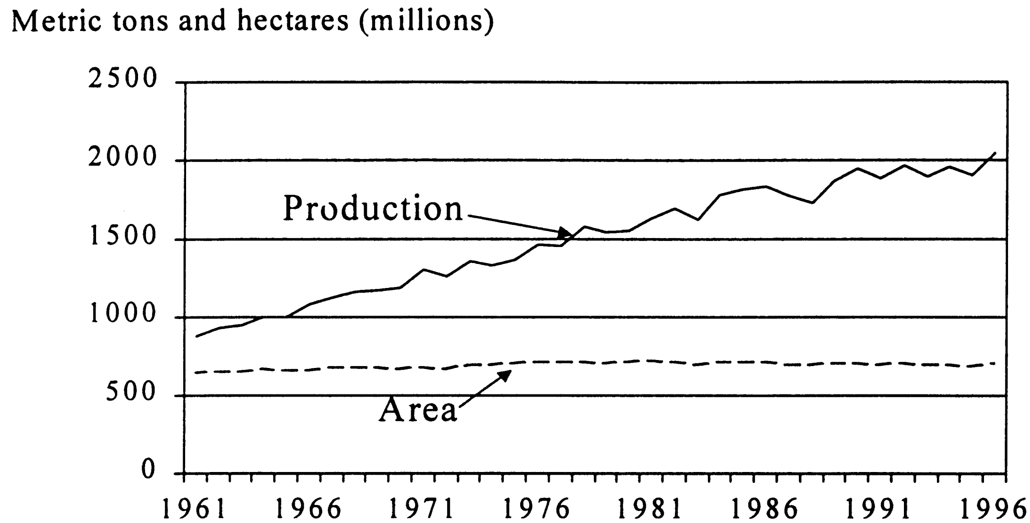
Source: FAO (1997).

The above data show rather stable consumption patterns across broad food groups over time. The major change is a reduction in pulses, roots, and tubers and an increase in livestock and livestock product consumption. Harvested yield, area, and production of the first five categories accounting directly for over 60 percent of food energy are analyzed in the following pages. A few numbers on production efficiency of livestock are presented, the major additional source of total calories.

Cereals

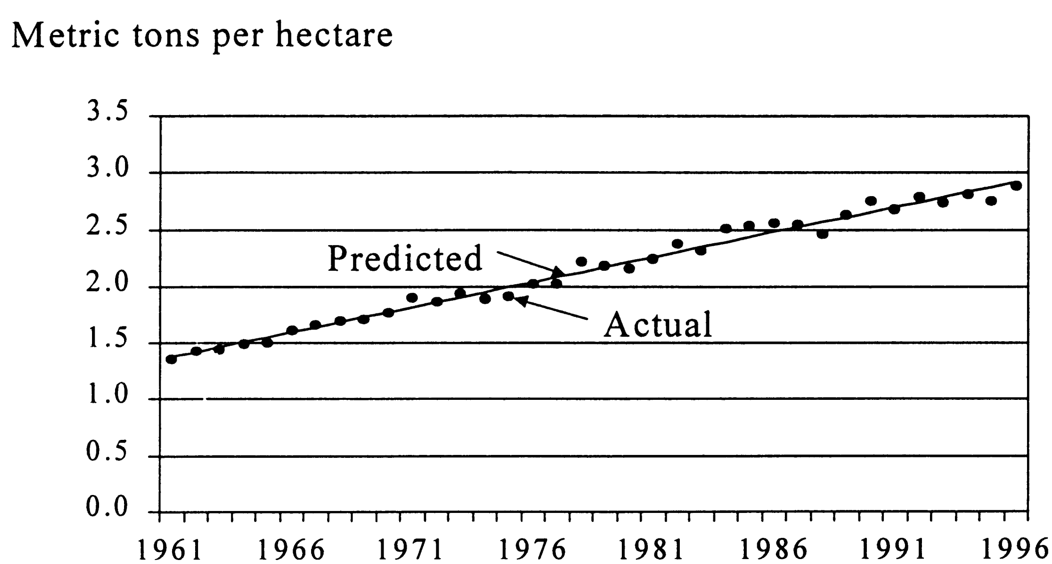
Cereals receive special attention because they directly or indirectly (through livestock) supply well over half of all food energy and are central to buffer stocks and transport essential for food security. Several observations are apparent from Figures 1a and 1b:

Figure 1a. World Cereal Area and Production, 1961-1996



Source: FAO (1997)

Figure 1b. World Cereal Yields, 1961-1996



% change	3.20	2.42	1.95	1.63	1.51

Source: FAO (1997).

- Almost all production expansion is from yields—global area in cereals was essentially the same in 1996 as in 1961 (Figure 1a).

- From 1961 to 1996, global cereal yields expanded around the straight line postulated by Malthus (Figure 1b). The rate of gain averaged 4.4 kilograms per hectare per year.

- Clusters are apparent of approximately five years of flat yields followed by a sizable yield gain.

- The linear yield line implies declining percentage rates of yield growth. For example, the 3.2 percent trend growth rate for cereal yield in 1961 fell by half to 1.6 percent in 1996. If global population continued to grow at the 2 percent annual trend rate of 1970, the portents for world food security would be onerous indeed (see Annex Table 2).

Vegetables and Melons

Harvested (including double-cropped) area of vegetables and melons, far smaller than that in cereals, increased only modestly in recent years (Figure 2a). In contrast, production has increased markedly, mostly the product of yields advances.

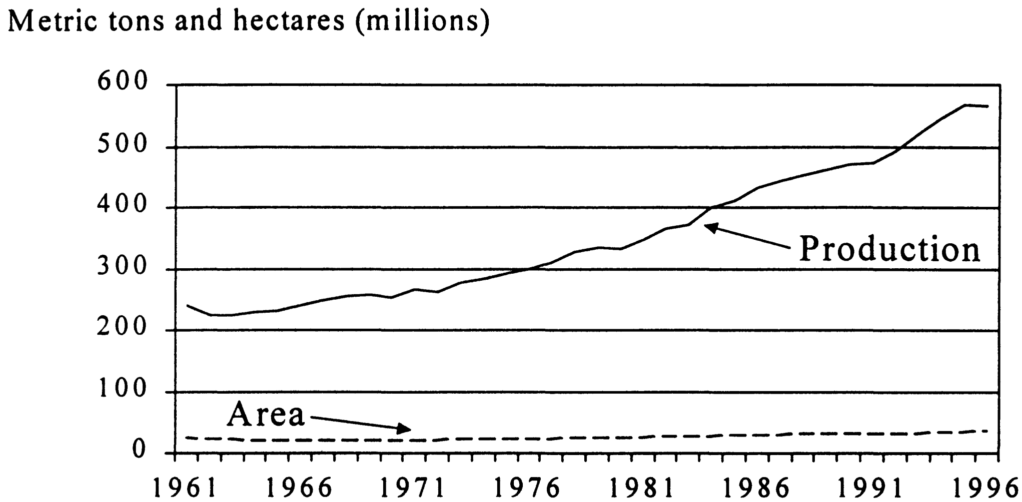
Additional observations are apparent from Figure 2b:

- Harvested yield gains for vegetables and melons not only fall short of those for cereals, they fall short of global population growth from 1961 to 1996.

- As with cereals, some clustering is apparent in vegetable and melon yields in Figure 2b. Such clustering could result from global weather patterns affecting several crops.

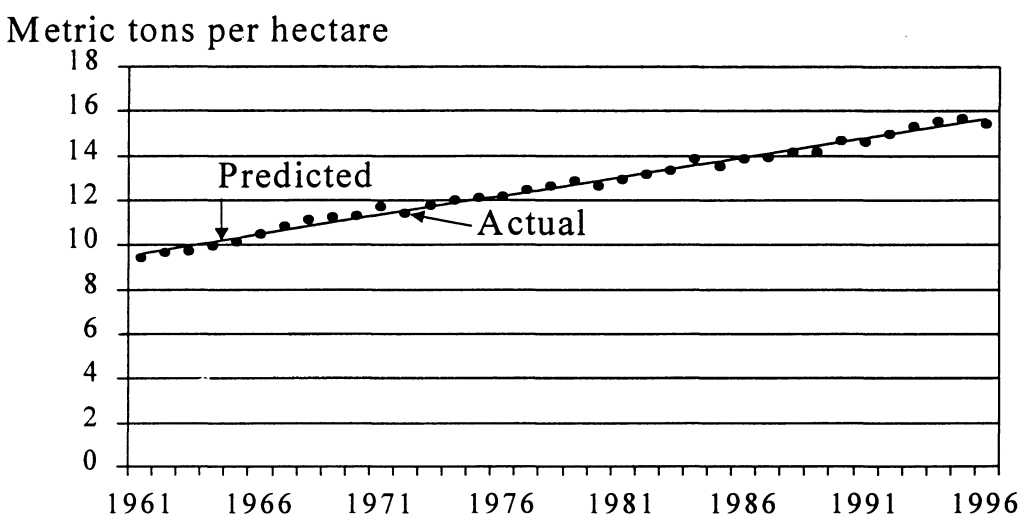
- A straight line fits the vegetable and melon yield data very well (adjusted $R^2 = 0.990$ versus 0.985 for cereals).

Figure 2a. World Vegetables and Melons Area and Production, 1961-1996



Source: FAO (1997)

Figure 2b. World Vegetable and Melon Yields, 1961-1996



% change 1.79 1.52 1.32 1.17 1.10

Source: FAO (1997)

• The annual percentage increases in yields of vegetables and melons are slowing but by much less than the halving apparent for cereals in Figure 1b between 1961 and 1991.

Pulses

Area in pulses rose sharply in the early 1960s, declined to 1980, and by 1996 rose to the same level as in 1963 (Figure 3a). Area was more variable than for cereals or vegetables but yields accounted for most of the 42 percent rise in world pulse production from 1961 to 1996.

Yields have progressed upwards but at a rate well short of increases for vegetables and cereals (Figure 3b). Trend yield gains not only have been slow, averaging less than 1 percent per annum since the 1960s, but also slowed in percentage terms—to 0.75 percent in 1996.

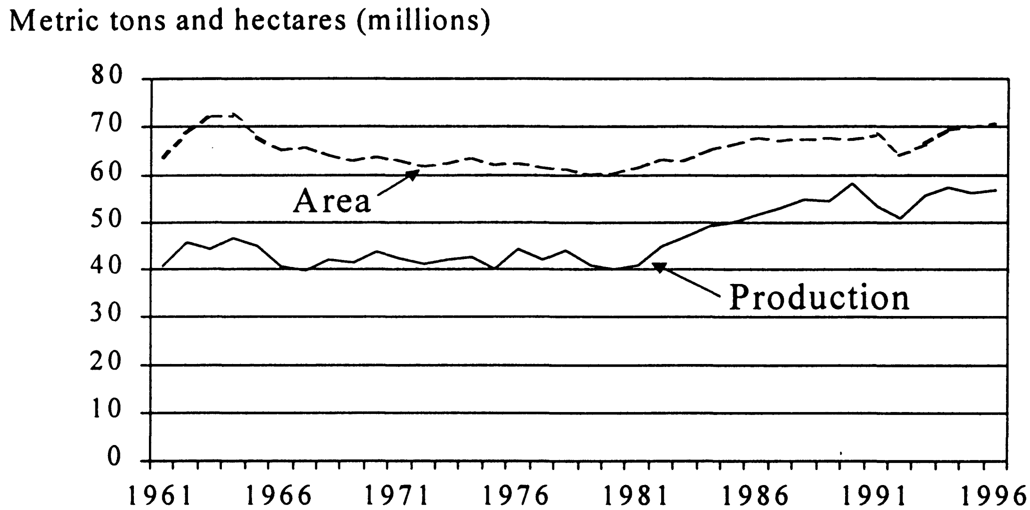
As with cereals and vegetables, pulse yields have followed a linear trajectory. To be sure, yield growth seemed to accelerate from 1980 to 1990. But yield in 1996 was lower than yield in 1990. There is little basis for projecting anything other than the linear historic trend of Figure 3b to future years.

Roots and Tubers

Roots and tubers provide 5 percent of global food calories, second only to cereals among crops. Production is somewhat variable but trends upward in Figure 4a. The rather stable area indicates that production changes have come mainly from yield variation.

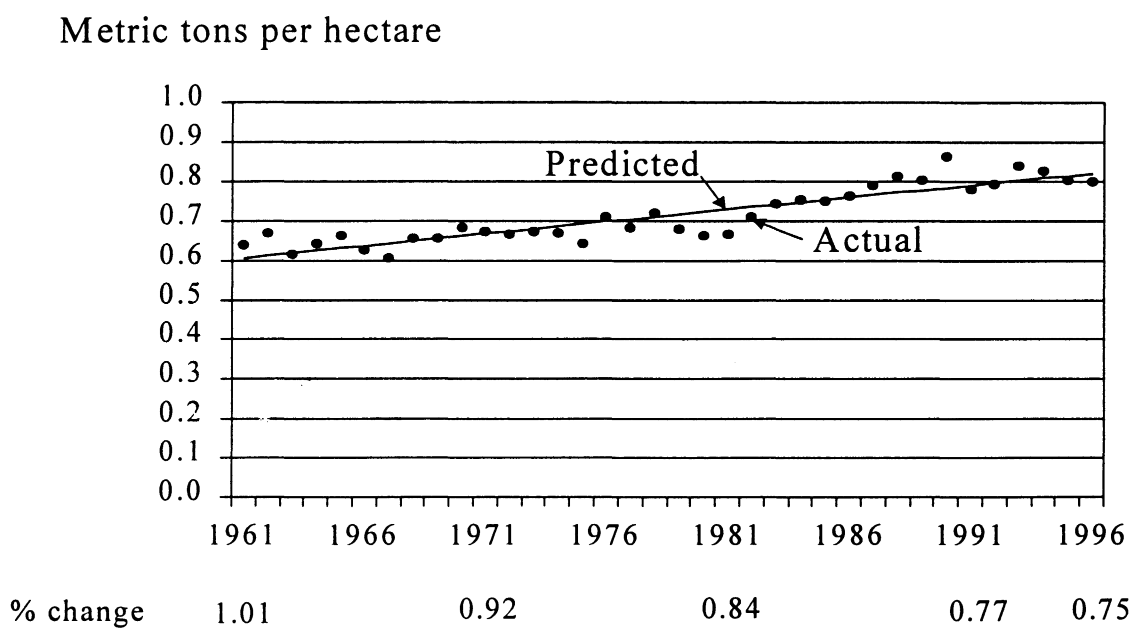
Production of roots and tubers per hectare is high (Figure 4b). Percentage yield increments are small, less than half population growth, and are below gains for cereals, vegetables, and pulses.

Figure 3a. World Pulses Area and Production, 1961-1996



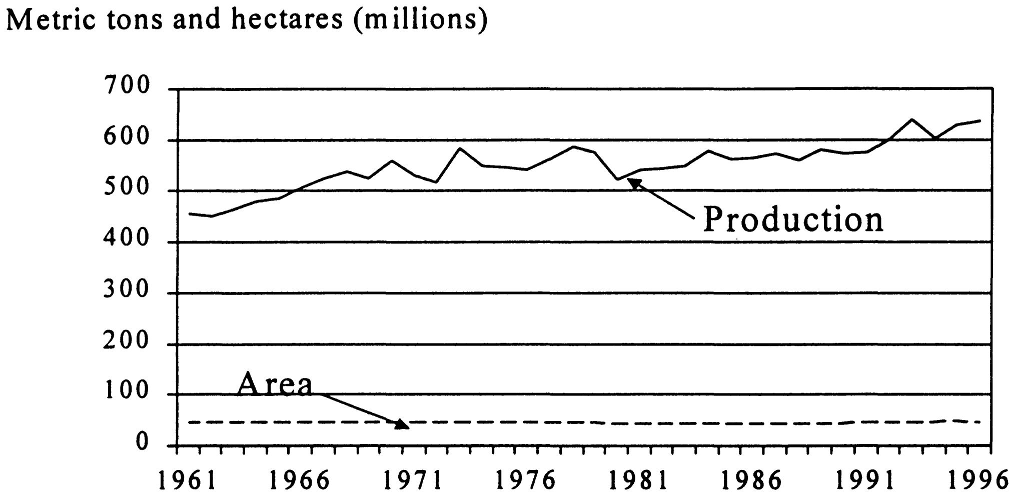
Source: FAO (1997)

Figure 3b. World Pulse Yields, 1961-1996



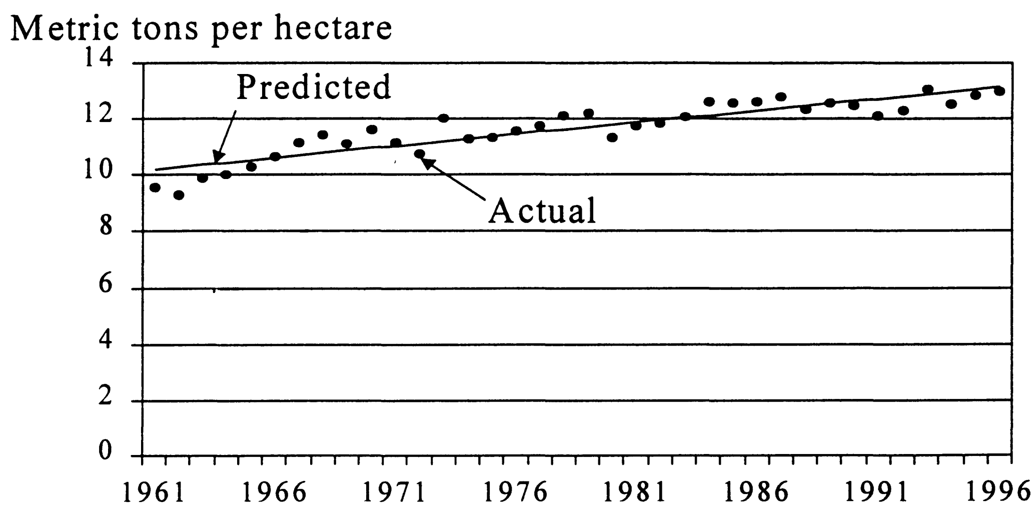
Source: FAO (1997)

Figure 4a. World Roots and Tubers Area and Production, 1961-1996



Source: FAO (1997)

Figure 4b. World Root and Tuber Yields, 1961-1996



% change	0.82	0.76	0.71	0.66	0.64

Source: FAO (1997)

No basis exists to reject the hypothesis of a linear yield trend in Figure 4b. The challenge will be to maintain the linear trend in the future given that yields were below trend in six of the seven most recent years of historic data.

Oilcrops

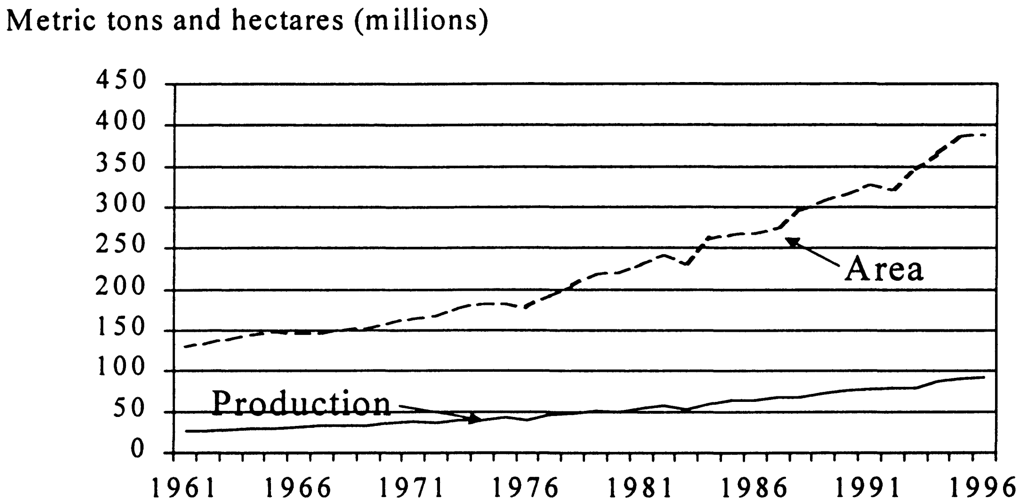
Oilcrops are the only major category of crops expanding in area (Figure 5a). Soybeans have expanded on area formerly in corn, oats, and cotton in the United States; canola or rapeseed has expanded on area formerly in wheat in Canada and in western Europe; and sunflower on lands in the Former Soviet Union. A large part of the new cropland in the Brazilian Cerrado has been planted to soybeans.

Because many oilcrops do not respond as well as other crops to intensive management (e.g., synthetic fertilizers, irrigation, hybrid seed), the production of oilcrops has expanded mainly from greater area rather than yield. Average yields of oilseeds have been low and annual percentage rates of increase have been slow (Figure 5b). As with other major categories of crops, oilcrop yields show no tendency to accelerate above the linear trend fitted to the data in Figure 5b. If anything, the historic trend indicates a slowing of yield growth. For example, yields through 1996 did not exceed the 1987 yield.

Livestock

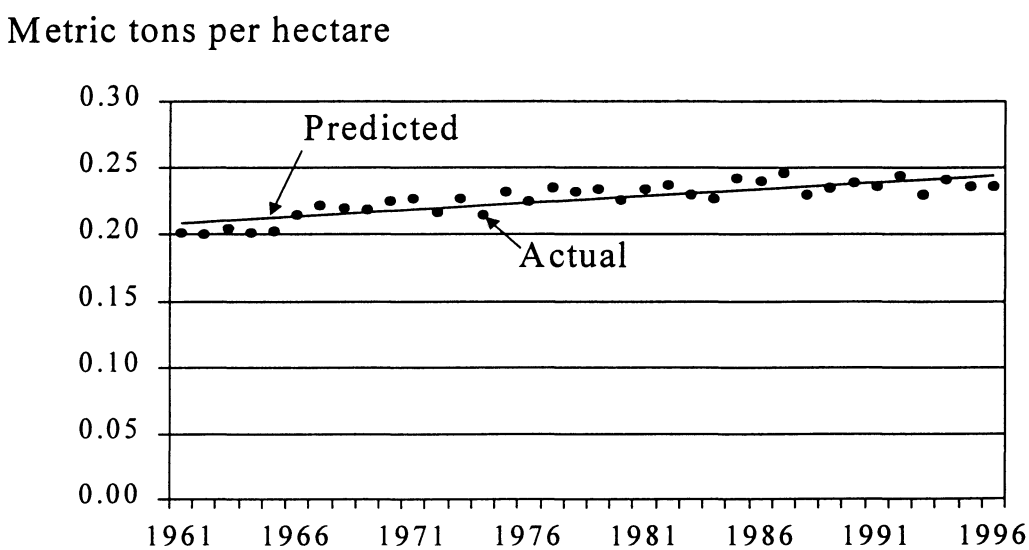
Data comparable to those for crops in Figures 1 to 5 are not available for livestock and livestock products. However, livestock offer only limited opportunities to expand productivity

Figure 5a. World Oilcrops Area and Production, 1961-1996



Source: FAO (1997)

Figure 5b. World Oilcrop Yields, 1961-1996



% change 0.49 0.47 0.45 0.43 0.42

Source: FAO (1997)

of agriculture. They require more resources per calorie of food than do crops. The U.S. Office of Technology Assessment (p. 18) projected the following growth rates in American animal production technology from 1982 to year 2000:

	Annual growth (%)
Pounds beef per pound feed	0.2
Pounds milk per pound feed	0.2
Pounds pigmeat per pound feed	0.6
Pounds poultry meat per pound feed	2.0

If these rates are representative of world conditions, they provide little optimism that livestock productivity gains will improve food security. Nonetheless, livestock remain an excellent means to utilize land unsuited for crops, provide a buffer for consumption when crops fail, provide high quality protein and other nutrients, and are a favored food as income rises. [1]

Comment on Yields

In summary, global yield trends for crops and measures of livestock feeding efficiency provide a sobering picture on this bicentennial of Malthus' *Essay*. The hypothesis cannot be rejected that global yields trends from 1961 to 1996 are linear. Malthus may be chuckling in his grave that for this era in history he is at least half right.

[1] Although grazing animals utilize land not critical for crops, up to 70 percent of that rangeland is degraded (Dregne and Chow, pp. 235–256). The analysts (p. 278) estimate that up to 50 percent of this rangeland could be restored at favorable benefit-cost ratios to produce more livestock. However, restoration is unlikely without stronger than current economic inducements.

Given yield trends and the lack of expansion in area, the trend in the other half of Malthus' thesis, *demand* for food, takes on a certain urgency. Can the disappointing yield trends depicted in the previous paragraphs keep up with future population growth? The challenge is sobering indeed given global population growth of 2.03 percent per year in 1970 and 1.74 percent per year in 1990 (see Annex Table 2).

Demand Trends

Demand for food is driven by two major components—population and income. Telling changes are occurring in population growth, the most important of these two drivers.

It took nearly all of the 4 billion years the earth has existed to reach a human population of 1 billion—in 1800. Gains since are as follows:

Year	World Population (billion)	Years to next billion
1800	1	125
1925	2	35
1960	3	14
1974	4	13
1987	5	12

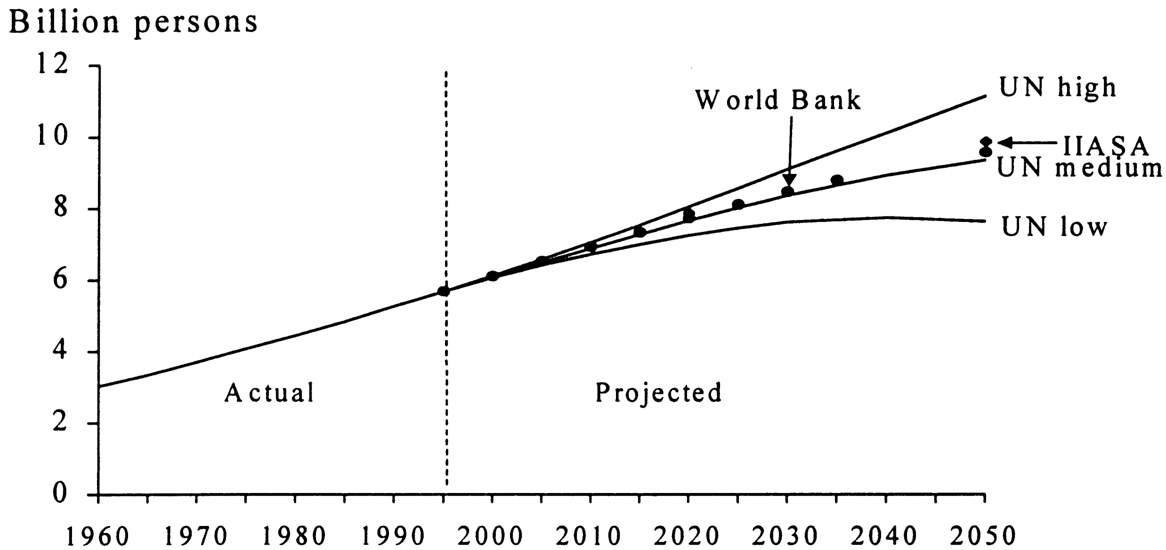
Source: Bos et al., p. 4

Adding the second billion people took 125 years (to 1925), adding the third took 35 years (to 1960) and adding the fourth billion took only 14 years (to 1974), indicating an accelerating (Malthusian) growth rate. The world is expected to add its sixth billion by year 1999 (Bos et al., p. 4).

Demographers are projecting a population trend turnaround: the world seems headed for zero population growth (ZPG) in the not too distant future. Population projections from the

United Nations (UN), World Bank (by Bos et al.), and International Institute for Applied Systems Analysis (IIASA by Lutz et al.) shown in Figure 6 all (UN medium) show somewhat similar future population and all projections are increasing at a decreasing rate.

Figure 6. UN, World Bank, and IIASA Global Population Projections



Source: see text.

Table 1 indicates the year and number of people when zero population growth is achieved as projected by the three agencies listed in Figure 6 and by Steven Mosher (p. A-16) and Dennis Avery (p.7). The five estimates for global ZPG range from year 2030 and 7 billion inhabitants by Mosher to year 2128 and 11 billion inhabitants by the World Bank.

Overall food demand depends on income as well as population. The single most likely scenario (see Annex Table 1) is for global aggregate food demand to increase 0.3 percent per capita annually on average due to rising incomes. At that rate, *per capita* food consumption gains by ZPG over 1995 range from 10 percent (Mosher, president of the Population Research Institute) to 49 percent (Bos et al. for World Bank). Adding the impact of population growth to income, total demand for food is projected to increase from 39 percent (Mosher) to 201 percent (Bos et al.) from the 1995 level before ZPG is reached. The latter estimate implies that food production will have to triple from 1995 levels before reaching global ZPG.

After reaching ZPG aggregate world food demand will continue to grow approximately 0.3 percent per year due to the income affect alone. With time, that income effect could be offset by population decline, causing overall food demand to stagnate or fall. The per capita income effect remains somewhat stable through time because the tendency for rising incomes and falling income elasticities to lower the rate is compensated by the rising share of global income growth in low income countries where income elasticities, though falling, remain sizable, and income growth per capita is rapid.

Other scenarios are presented in Table 1 recognizing that per capita food demand could grow as little as 0.2 percent or as high as 0.4 percent on average annually. The 0.2 percentage rate could occur if higher food prices slow demand growth. Based on these income scenarios, overall food demand could grow as little as 34 percent (Mosher, 0.2 percent/capita assumption) or as much as 243 percent (Bos et al., 0.4 percent/capita assumption) before ZPG is reached (Table 1).

Higher real food prices (a reversal of the historic price trend) could attract more technology and resources including land to meet food demand. Considering only the 0.3 percent per capita food demand growth scenario, the 39 percent total food growth demand to ZPG implied by Mosher poses no challenge to the food system; in contrast, the 201 percent growth implied by Bos et al. signals a major challenge—the need to triple food output from current levels. Under the latter high demand scenario, productivity advances would be especially important to avoid sharply higher food prices and extension of cropland to fragile soils.

It is notable that the Avery prediction implies the largest *annual* average rate of food demand increase to ZPG, 1.36 percent—well above the lowest annual rate, 0.83 percent by Bos et al.[2] The fewer years to reach ZPG compensate for the smaller demand increase implied by Avery, causing average annual food demand growth to be sizable. Of course, food production is volatile from year to year so that averages for the 1995–2050 period in Table 1 veil possibly large transitory supply-demand imbalances.

At issue is whether the total and annual demand increases shown in Table 1 will cause real food prices to rise—given the productivity trend measured, albeit imperfectly, by yields in Figures 1b to 5b. To address that issue, Figure 7 summarizes supply (yield) and food demand trends graphically by decade to year 2050. Supply is assumed to increase from yields rather than from additional area in production. Projected rates of yield gain are merely extensions of the linear yield line shown earlier in Figures 1b to 5b. Population estimates are the medium UN projections.[3]

Three supply/demand balance periods are apparent in Figure 7: the first is from 1950 to 1980, when grain yield gains on average exceeded demand gains mostly by a wide margin.[4] Real food prices fell sharply and reserve capacity accumulated as diverted acres, storage stocks, and subsidized exports. The trend reversed in the 1980s, but America had enough reserve capacity in commodity stocks and diverted acres to avoid rising real food prices. Real prices of

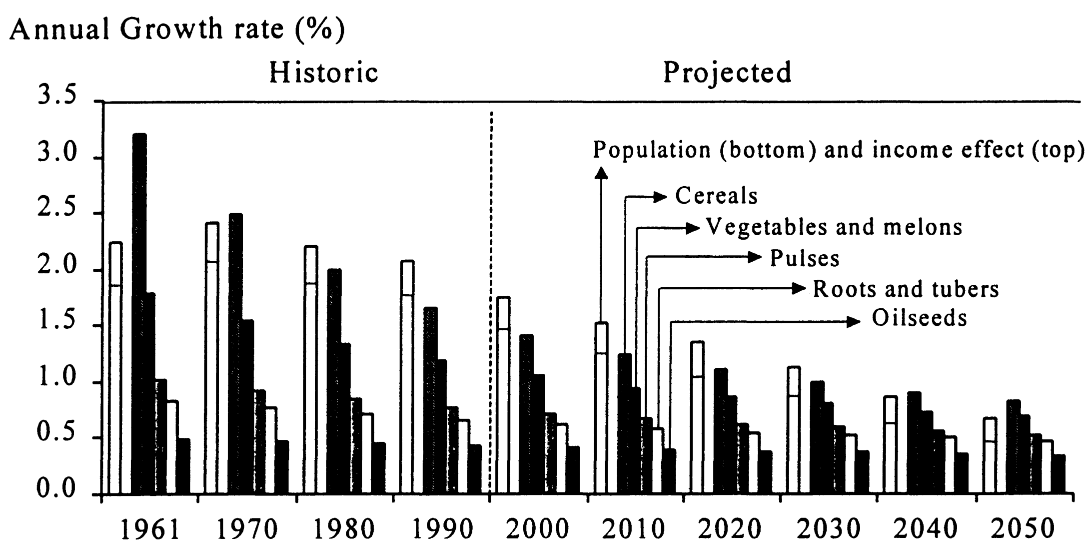
[2] As apparent from Annex Table 2, the average population growth rate projected by Bos *et al*. exceeds that projected by Mosher or Avery over the years to ZPG expected by the latter analysts.
[3] Population forecasts by Avery and Mosher are omitted from Figure 7 because they do not provide population estimates prior to ZPG.
[4] 1950s yields are not shown but are essentially linear extensions of the straight lines shown in Figures 1b to 5b back to 1950 (see Mitchell *et al*, pp. 50, 51).

Table 1. Total and annual food demand growth to ZPG from 1995[a]

			Per capita food demand increasing:[c]					
			0.2%/year		0.3%/year		0.4%/year	
	ZPG	Years to	Demand growth		Demand growth		Demand growth	
Study	Population[b]	ZPG[b]	Total	Annual	Total	Annual	Total	Annual
	(billion)	(Year[s])	(Percent)					
Mosher	7.0 (year 2030)	35	34	0.84	39	0.94	44	1.04
Avery	9.0 (year 2040)	45	76	1.26	84	1.36	92	1.46
IIASA (Lutz)	10.5 (year 2084)	89	124	0.91	144	1.01	167	1.11
UN (medium)	10.3 (year 2094)	99	124	0.82	147	0.92	173	1.02
World Bank (Bos et al.)	11.3 (year 2128)	133	163	0.73	201	0.83	243	0.93

Source: see text.
[a]1995 world population 5.6 billion.
[b]When data from the source was incomplete, the ZPG population and year was projected using a quadratic equation fitted to available data.
[c]See Annex Table 1.

Figure 7. Global Demand Growth Rates (from Income and Population) Contrasted with Crop Yield Gains



Source: Population projections from United Nations
Yield data from FAO (1997)

farm commodities in aggregate in the United States have fallen little since the mid-1980s, however, being only 4 percent lower in 1996 than in 1986 (Council of Economic Advisors, p. 412).

Now that America's reserve capacity of diverted cropland, accumulated stocks, and subsidized exports is spent, a second era, one of potential food insecurity, is apparent to 2030. On average, demand is projected to increase faster than yields. Without yield advances in excess of those anticipated, real prices for farm food ingredients are likely to rise to draw more land and other resources into food production.

A third period emerges after 2030. World demand is expected to increase 0.87 percent per year (medium UN population, 0.22 percent per capita demand growth) in 2040 and 0.68 percent per year in 2050, somewhat less than projected annual grain yield growth of 0.91 percent in 2040 and 0.83 percent in 2050 (see Annex Table 2).

Conclusions and Caveats

The prospect of rising food prices is real, but is no basis for panic or complacency. In year 2000, demand growth is likely to exceed cereal yield growth by only 0.3 percent per year and all crop and livestock yield growth by 0.5 percent per year.[5] Assuming an intermediate run price flexibility of aggregate demand for food of –3, a 0.5 percent global excess food demand growth would raise the price of farm food ingredients 1.5 (i.e., 3 x 0.5) percent. The shortfall of yield growth below demand growth is less and hence price increments less for subsequent years

[5] Crops and livestock other than those in Figures 1 to 5 are assumed to grow at 1.28 percent per year, the same rate as projected yields from Figures 1b to 5b weighted by calorie share.

because of slowing population growth.

The predicted tighter supply-demand balance over the next three decades does not imply a "Malthusian" future of starvation and other pestilence although famine may occur in some areas of the world as in past decades due to local civil unrest. And the world could experience more frequent food price spikes as occurred in 1973-74, but incidence and severity of food shocks can be reduced by more open trade and by sound economic policies for broad-based sustainable development in poor countries (see Tweeten and McClelland). Output of food may need to double and possibly triple before zero population growth is achieved, but that target is attainable even with present technology as people would consume less meat and producers would invest more in production inputs, improved technology off the shelf, and the like in response to higher prices.

Although real farm level food prices may rise in developed and developing countries on average for the next three decades, any increase is likely to be readily absorbed and indeed hardly noticed by consumers in developed countries. Americans, for example, on average spend only 2–3 percent of this income on farm food ingredients. Even a doubling (absurd) of farm food ingredient prices could reduce consumers' real income only 2 percent. However, rising real food prices are a hardship for low income families at home and abroad because they spend a much higher proportion of their income on food than does the average American family. Farmers benefit from price increases, but are cautioned against excessive bidding for land. Instability will continue to be the major economic problem for commercial farmers, and cyclical downturns in economic conditions could punish land market plungers.

The major hardship would be on food insecure countries. Such countries, being poor, would face a challenge bidding against other industrialized countries for food. The most serious situation is sub-Saharan Africa which appears to be losing the capacity to feed itself. It is notable, however, that Africa's falling per capita food production is not the result of production gains lagging behind other regions (Mitchell et al., pp. 50, 169), but rather their little progress in movement through the demographic transition to lower birth rates.[6] Rosegrant et al. (p. 15) project sub-Saharan Africa's net imports of cereals will increase from 9 million tons in 1990 to 26 million tons in year 2020 or by nearly 4 percent per year. Financing such imports will be a challenge indeed. Of course, developing countries that are net exporters of food will gain from higher food prices. But many export coffee, cocoa, and tea—items which may not share in general food price gains.

Readers can examine the data in this study and form their own conclusions regarding future food security. However, several caveats are offered regarding the analysis.

- This study focused on yield trends because yields especially can be influenced by investments in science and technology, but some may look to opportunities for expanding aggregate cropland area as a serious omission from the analysis. However, opportunities to expand food production net area are limited because the most productive and environmentally sound land already is devoted to agriculture or other higher value uses. Additional productive land brought into food production in Africa, South America, or elsewhere will tend to be offset by losses of land to forest, recreation, reservoir, road, urban development, and other non-agricultural uses. Similarly, new irrigated land will be partly offset by irrigated land and water lost to water logging, saltation, declining water tables, cities, and to other uses.

Whereas individual crop area can respond to changing prices among crops by replacing

[6] Cereal yields increased on average only 1.4 percent per year in Africa compared to 1.6 percent in Latin America and 2.3 percent in other major world regions from 1950 to 1990 (Mitchell et al., pp. 50, 51. Hence Africa kept up with world production gains only by using considerable additional conventional resources such as land and labor.

area in another crop, *aggregate* cropland area response to price is low. Heady and Tweeten (p. 440) estimated that each 10 percent increase in the ratio of prices received to prices paid by farmers increased aggregate U.S. cropland area by only 0.5 percent in one to two years. Long-term supply response is double the short-run response. Thus if producers expect favorable crop prices to last, then a 10 percent improvement in real food price increases crop area 1 percent in the long run according to Heady and Tweeten's results. It follows that a significant expansion of cropland area would require expectations of a sustained, large increase in real crop prices.

- Is extending the linear past yield trend likely to overestimate or underestimate actual future global food growth? New technologies such as bioengineering may accelerate yield gains, but matching the past and in many instances unrepeatable contributions of animal breeding, hybrid crops, fertilizers, pesticides, and irrigation will be challenging indeed. Conservation tillage and many products of biotechnology such as Bt corn and Roundup-Ready soybeans aim as much or more to reduce production costs as to raise yields. Further productivity gains become more elusive as the harvest index (grain per unit of plant biomass) and feeding efficiency (pounds of feed per pound of gain) approach biological limits. Consequently, the percentage rates of annual yield gains in agriculture seem destined to continue to fall. Much maintenance research will be required merely to sustain current yields in the face of growing disease and pest resistance. In short, future yields seem as likely to fall below as to rise above historic trends.

- The study uses harvested rather than planted area and yields. Planted area and yields, if available, could have improved the analysis by indicating whether higher yields resulted from abandoning marginal areas in years of unfavorable weather. As area expands to more marginal lands and double cropping, yields can be expected to fall, *ceteris paribus*. This tendency to extend crops to marginal areas in response to higher food prices is another reason why economic pressure to expand production is unlikely to raise future yields above the linear trends extrapolated from Figures 1b to 5b.

- To discern how investments in science and technology could influence future production of food, ideally we would like to trace productivity (output per unit of conventional production inputs) rather than yields. At issue is whether yields overestimate or underestimate productivity gain. Yields almost certainly overestimate productivity gain because higher yields come partly from greater application of conventional production inputs (more irrigation water, harvest labor, unimproved capital, etc.) and not just from productivity enhancing non-conventional inputs such as education, research, extension, and other dimensions of science and knowledge. This conclusion reinforces a thesis of this report—that the percentage rate of productivity gain in agriculture is slowing. Attention to investments in science and technology expanding crop yields is important, not only to lessen the impact of what is likely to be a tighter supply-demand balance than in previous decades, but also to protect the environment (Avery and Avery).

- Many governments worldwide have been neglecting investment in agricultural science—sub-Saharan Africa, for example, spends only 0.5 percent of its agricultural Gross Domestic Product on agricultural research (Pinstrup-Andersen, p. 5). A considerable lag occurs after investments in education, research, and extension before gains show up in agricultural productivity. On average, nearly a decade is required before an investment in research to improve agricultural productivity has its peak payoff and after another decade the gains fall to zero because of resistance buildup in pests, replacement by alternative technologies, or other reasons (Braha and Tweeten, p. 10). Hence, considerable investment in maintenance research is required merely to sustain crop yields. Although rising global real prices for farm food ingredients will be difficult to avoid over the next decade or more, additional investments in agricultural science undertaken now can reduce unfavorable longer-term food-cost consequences of the tighter supply-demand balance.

- Cotton is omitted from this food analysis because it is a fiber. But its seed provides an edible oil and meal and it competes with food crops for land. Harvested area of cotton is sizable and fairly stable from year to year. Harvested cotton area was approximately 32 million hectares in 1961 and 1996. Trend annual percentage yield gains ranging from 2.7 in 1961 and 1.4 in 1996 place it behind only cereals and ahead of other major crops and livestock. Given expected continuing strong demand for cotton and average productivity growth, the crop does not appear to offer much opportunities for food crop expansion at its expense.

- Other studies are divided on the long-term food price outlook, but many analysts anticipate falling real food prices (Mitchell and Ingco for World Bank; Rosegrant et al for International Food Policy Research Institute) or constant (Alexandratos for FAO) despite recognition by these studies of falling percentage rates of yield increase and little change in crop area. Other analysts (Brown, 1991, 1995; Brown and Kane) expect the real price of food to increase. Experimental results under controlled conditions do not point to emerging technologies radically altering yield trajectories from those depicted in this study (Barnett et al.).

- The final and most obvious caveat is that distant predictions become especially unreliable. That unreliability could, of course, result in a more or less favorable food supply-demand balance than depicted in this analysis. For example, realization of the high UN population projection would place a severe strain on food production capacity. And twenty-first century crop area could drop unexpectedly below current levels. Environmental and natural resource constraints such as soil erosion, rock phosphate depletion, and rising energy costs also could constrain production in later years. Too little might be invested in science or consumers and voters could reject bioengineered foods, slowing productivity gains.

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Annex Table 1. Calculation of annual per capita increase in food demand.

Country Classification	Population[a]	Income per capita[b]		World income share[c]	Income elasticity of demand[d]	Per capita food increase from income[e]	
		Total[b]	Increase				
	(million)	($)	(% incr/yr)			(%/yr.)	
		1994				unweighted	weighted
Low income	3,185	380	3.0	0.048	0.6	1.8	0.0864
Middle income	1,570	2,520	0.8	0.158	0.3	0.5	0.0853
High income	850	23,420	1.2	0.794	0.1	0.1	0.0953
				1.000			0.2670
		2050					
Low income	6,206	1,989	2.1	0.189	0.5	1.1	0.1985
Middle income	2,075	6,843	1.3	0.217	0.2	0.3	0.0564
High income	850	45,677	0.8	0.594	0.05	0.04	0.0238
				1.000			0.2787

[a]World Bank, p. 194. Population growth estimated from United Nations, Annex II.
[b]World Bank, p. 188.
[c]Population times income per capita as share of world total.
[d]Updated estimates from Mellor, p. 64.
[e]Product of income increase/year. X income elasticity of demand (unweighted). X world income share (weighted).

Annex Table 2. World crop yield and demand (population and income per capita) trend growth rates by selected years.

	Historic				Projected					
Yield or demand	1961	1970	1980	1990	2000	2010	2020	2030	2040	2050
					(Percent per year)					
Supply										
Crops (Figures 1-5)[a]										
Cereals	3.20	2.48	1.99	1.66	1.42	1.25	1.11	1.00	0.91	0.83
Vegetables and melons	1.79	1.54	1.34	1.18	1.06	0.95	0.87	0.80	0.74	0.69
Pulses	1.01	0.93	0.85	0.78	0.72	0.68	0.63	0.60	0.56	0.53
Roots and tubers	0.82	0.77	0.71	0.66	0.62	0.59	0.55	0.52	0.50	0.47
Oilseeds	0.49	0.47	0.45	0.43	0.41	0.40	0.38	0.37	0.35	0.34
Total (weighted average)	2.78	2.18	1.77	1.49	1.28	1.14	1.01	0.92	0.84	0.77
Demand										
Population										
IIASA (Lutz *et al.*)	1.83	2.03	1.85	1.74	--[b]	1.47	1.13	0.87	0.67	0.51
UN (medium)	1.83	2.03	1.85	1.74	1.44	1.24	1.08	0.88	0.65	0.48
World Bank (Bos *et al.*)	1.83	2.03	1.85	1.74	1.47	1.28	1.09	0.91	0.68	0.57
Income effect (see Annex Table 1)	0.40	0.38	0.36	0.33	0.31	0.29	0.27	0.24	0.22	0.20
Total demand UN pop. plus income	2.23	2.41	2.21	2.07	1.75	1.53	1.35	1.12	0.87	0.68
Excess demand										
Demand less yield gain	c	c	c	c	0.47	0.39	0.34	0.20	0.03	-.09
Price impact										
Price flexibility (3.0) times excess demand	c	c	c	c	1.41	1.17	1.02	0.60	0.09	-0.27

[a]Extension of linear trend from Figures 1b to 5b.
[b]Not predicted for year 2000.
[c]Not included because depended on stocks, diverted area and other considerations not considered in this study.